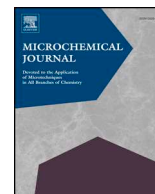




Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



A rapid screening method for testing the efficiency of masks in breaking down aerosols

Luca Amendola^{a,*}, Maria Teresa Saurini^a, Francesco Di Girolamo^a, Fabiana Arduini^{b,*}

^a ARPA Lazio, Regional Agency for Environmental Protection, via G. Saredo 52, 00173 Rome, Italy

^b Tor Vergata University, Department of Chemical Science and Technology, via della Ricerca Scientifica, 00133, Rome, Italy

ARTICLE INFO

Keywords:

Non-medical face masks

Medical face masks

TNT

Optical particle counter

Novel coronavirus SARS-CoV-2

ABSTRACT

The highest risk of novel coronavirus SARS-CoV-2 to be spread through human-to-human transmission has boosted the use of personal protective equipment at worldwide level. In Europe, the medical face masks must be tested to certify the essential requirements in agreement with European Standard EN 14683:2019, and face masks for industrial use in agreement with European Standard EN 149:2009. Due to the need of large quantitative of medical and non-medical face masks in coronavirus outbreak, several Italian industries are working for shift a portion of their manufacturing capacity for producing medical and non-medical face mask. For screening evaluation of the effectiveness of personal protective equipment produced by reconverted industries, ARPA Lazio and the Department of Chemical Science and Technologies of Tor Vergata University have set-up an analytical system able to simulate the respiratory action and to measure the percentage of particles that pass through the face masks using optical particle counter (based on the EN 16890: 2017 that uses the same light scattering principle to evaluate the filter filtration efficiency). This set-up was challenged using face masks produced by reconverted industries and the data were compared with ones obtained using medical face mask.

1. Introduction

In 19 March 2020, World Health Organization has produced a document related to the use of medical masks in areas affected by novel coronavirus SARS-CoV-2 intended for control professionals, healthcare managers, healthcare workers, and community health workers [1]. Regarding the use of face masks for civilians, World Health Organization and U.S. Centers for Disease Control and Prevention have both said that only people with COVID-19 symptoms and those caring for them should wear masks [2]. In details, World Health Organization suggested to maintain at least 1 metre (3 feet) distance between yourself and anyone who is coughing or sneezing as one of the basic protective measures against the new coronavirus [3], while U.S. Centers for Disease Control and Prevention suggested about 6 feet or 2 meters distance from others [4]. An interesting article has been recently published by L. Bourouiba in which she highlighted that “these distances are based on estimates of range that have not considered the possible presence of a high-momentum cloud carrying the droplets long distances”, taking into account that spread during exhalations, sneezes, and coughs encompasses mucosal droplets following short-range semiballistic emission trajectories and multiphase turbulent gas cloud, as well. The author reported “For these and other reasons, wearing of appropriate personal protection

equipment is vitally important for health care workers caring for patients who may be infected, even if they are farther than 6 feet away from a patient” [5]. Furthermore, van Doremalen et al. published in The New England Journal of Medicine on 16 April 2020, a study regarding aerosol stability of SARS-CoV-2 compared with SARS-CoV-1, demonstrating that the results obtained “indicate that aerosol and fomite transmission of SARS-CoV-2 is plausible, since the virus can remain viable and infectious in aerosols for hours and on surfaces up to days (depending on the inoculum shed)” [6]. In this overall scenario, the Guardian reported on 1 April 2020 that World Health Organization considers changing guidance on wearing face masks because new evidence suggests wearing masks in public could help contain the pandemic [7]. In addition, Leung et al. reported in the article published in Nature Medicine on 03 April 2020 that “Our results indicate that surgical face masks could prevent transmission of human coronaviruses and influenza viruses from symptomatic individuals” [8].

Taking account the need of face masks for a huge number of people, some countries have to face the issue of insufficient amount of personal protective equipment. In Italy, this deficiency has boosted several industries to reset their production chain, moving from their usually target manufacturing towards the production of personal protective equipment in order to match the large quantities requested for the

* Corresponding authors.

E-mail addresses: luca.amendola@arpalazio.it (L. Amendola), fabiana.arduini@uniroma2.it (F. Arduini).

<https://doi.org/10.1016/j.microc.2020.104928>

Received 6 April 2020; Received in revised form 12 April 2020; Accepted 12 April 2020

Available online 03 May 2020

0026-265X/© 2020 Elsevier B.V. All rights reserved.

safety of citizens. This urgent request is encountering a barrier, which entails the customization of the production to delivery effective medical and non-medical masks.

In this regard, it is important to distinguish between medical masks for healthcare professionals and civil protection workers (FFP2 and FFP3) and non-medical masks for civilians. The production of medical masks needs to respect the following European Standards namely i) EN 14683:2019 for the surgical masks – Requirements and test methods which reports specification of construction, design, performance requirements and test methods for medical masks with the aim to limit the transmission of infective agents from staff to patients during surgical procedures; ii) EN 149:2009 for the respiratory protective devices FFP2 and FFP3 able to protect against particles the operator and not the patient. These mask filters inhaled air but did not exhale air [9].

Any other mask available on the market, is not a medical device or an individual protection device; to this purpose, this type of masks can be produced based to the art. 16, paragraph 2, of the Italian Legislative Decree 18/2020, under the responsibility of the manufacturer who must in any case guarantee the safety of the product: the materials used not cause irritation or any other harmful effect on health, are not highly flammable, etc. These masks cannot be used in a hospital or healthcare environments as they do not have the technical requirements of medical devices and personal protective equipment.

In 2002/657/CE concerning the performance of analytical methods and the interpretation of results, European Commission has defined screening method as “*methods that are used to detect the presence of a substance or class of substances at the level of interest. These methods have the capability for a high sample throughput and are used to sift large numbers of samples for potential non-compliant results. They are specifically designed to avoid false compliant results*” [10]. The screening methods was then established as useful analytical tools for rapid and cost-effective analysis rendering the value chain of measure more sustainable; indeed more analyses using screening methods rely on less analysis using confirmatory methods, that required large and expensive instrumentation, combined with skilled personnel [13].

To face the delivery of safe face masks in timely fashion, ARPA Lazio together with Department of Chemical Sciences and Technologies of Tor Vergata University have collaborated to set-up a screening analytical system for fast evaluation of the capability of this type of masks to break down aerosol, inspired by the activity of other groups [11,12]. Herein, we describe the set-up developed to deliver a smart analytical system able to simulate the inhalation and exhalation and measuring the aerosol able to pass through the face masks tested.

2. Experimental section

2.1. Reagents

Different types of face masks (Fig. 1) were kindly supplied by companies whose names are omitted to avoid any form of publicity. The medical masks were bought at local pharmacy.

2.2. Equipment

Analytical Instruments Air Cube Gas was used to create a constant flow at 6 L/min while FAI OPC optical particle counter was used to measure the particles before and after the aerosol passes through the masks.

2.3. Procedure

To evaluate the breaking down of aerosol through the face masks, a system was built in laboratory creating two chambers divided by the tested face mask. The first chamber (chamber 1, highlighted in red in Fig. 2B) can be opened to load it with aerosol, while the second one (chamber 2, highlighted in green in Fig. 2B) is closed and connected to

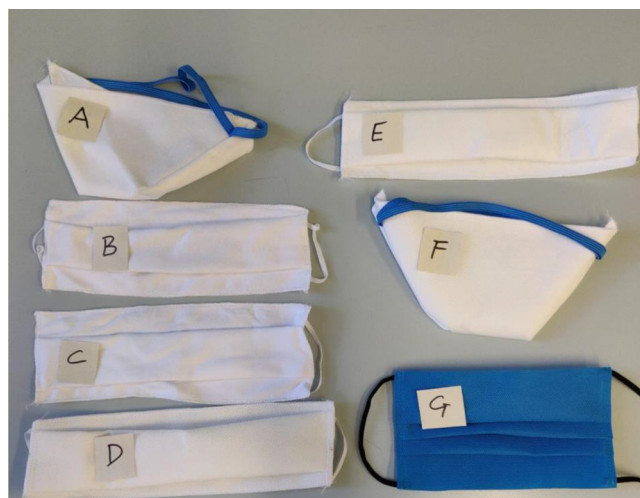


Fig. 1. Face masks tested.

vacuum pump for simulating the respiratory action. The percentage of particles blocked by face mask tested is evaluated measuring the particles in chamber 1 (loaded with aerosol) and the particles in chamber 2, after the simulated respiratory action, by the optical particle counter.

The detailed procedure is shown in Fig. 2. In phase 1, the chamber 1 is filled with aqueous aerosol produced by a commercial ultrasonic vaporizer (Fig. 2A), and the particles present are measured by the optical particle counter (Phase 2, Fig. 2B). After, the vacuum pump is switched on for 2 seconds simulating a deep respiratory action (Phase 3, Fig. 2C) which boosted the moving of the particles from chamber 1 to chamber 2, passing through the face mask. Then, the passed particles in chamber 2 were measured (Phase 4, Fig. 2D). The particle counter is able to detect particles starting from eight different dimensional ranges: 0.28, 0.4, 0.5, 0.7, 1.1, 2.0, 3.0, 5.0 μm . For each range, the effectiveness of face mask for breaking down the aerosol was evaluated using the following equation: $\%Eff = (N_i - N_f) / N_i \cdot 100$ where N_i is the count of the particles in chamber 1, while N_f is the count of the particles in chamber 2. Figure 2 shows the system made with material readily available in the laboratory; the same apparatus, made of methacrylate and equipped with the remote control of the aerosol, provides the same results.

The face masks were tested in the inhalation and exhalation direction, by setting the face mask in the conventional use or in opposite side.

The analysis conditions were chosen in order to create in chamber 1 an atmosphere heavily contaminated by aerosol particles. The flow rate of 6 L/min for 2 sec was chosen to simulate a deep single respiratory action. The acquisition time of the particle counter was set at 1 min to deliver reproducible measurements.

3. Results and discussion

To assess the effectiveness of face masks, at least 8 measurements for each type of masks were carried out, evaluating both the response in inhalation and exhalation using different masks of the same batch. In Table 1, the average filtration efficiency was reported taking into account the particles with diameters greater than 0.28 μm . The results obtained showed that the medical face mask is characterized by values higher than 97%, while only the face masks fabricated with three layers mainly constituted by TNT (non-woven fabric material) are able to reach values higher than 95%. These results are in agreement with a technical note of Politecnico di Milano which suggested the use of three layers and TNT as material [12].

To highlight the behavior of the breaking down of the aerosol particles at different dimensions, in Table 2 we reported all dimension

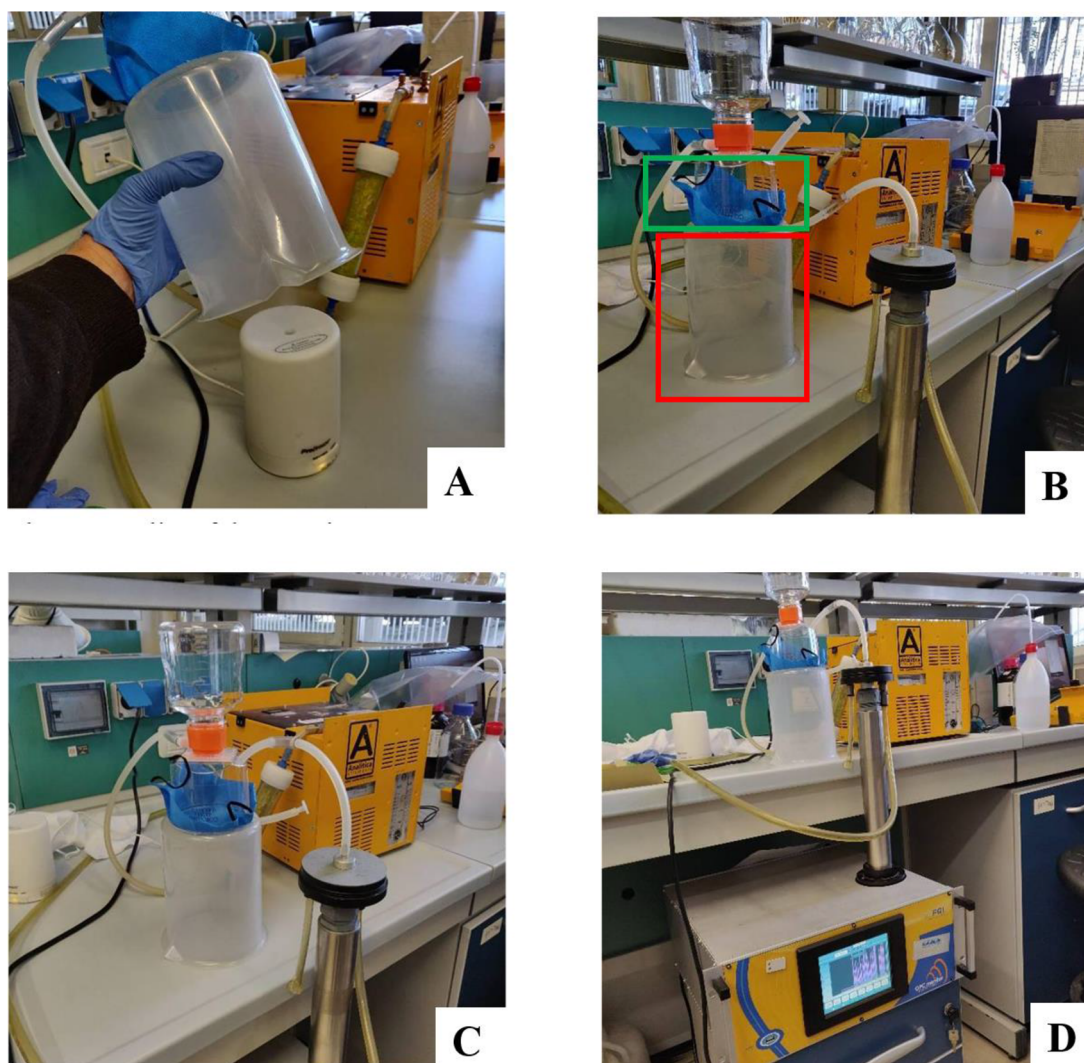


Fig. 2. Procedure for evaluating the effectiveness of face masks.

ranges of particles analyzed before and after the passing through the medical mask, non-medical masks type C and type D. As depicted in Table 2, the higher efficiency was observed at the higher particle dimensions. In addition, we reported also the measurement obtained when nitrogen was flown in chamber 2, observing a decrease of particles inside the chamber, as expected. The results obtained demonstrated that this method is able to discriminate easily the face masks suitable for aerosol breakdown, suggesting that it can be used as a screening method to evaluate the produced face masks in this urgency situation, in order to customize easily their production.

4. Conclusions

The issue of COVID-19 is having a huge impact of in different sectors ranging from health system to agriculture. In Italy, the deficiency of the medical face masks for the people involved in health system as well as of the non-medical face mask for the civilians has boosted several Italian industries to change their value chain for medical and non-medical face mask fabrication. To deliver medical face masks, the produced masks needed to be subjected to different tests following the European Standards namely EN 14683:2019 and EN 149:2009 which required complex laboratory set-up and long analysis time. Herein, we reported a set-up developed for screening analysis of medical face

Table 1

Average values of total particle size fraction ($>0.28 \mu\text{m}$) using face masks.

Sample	Material	Material %Eff. $>0.28 \mu\text{m}$ inhalation 4 measurements	Material %Eff. $>0.28 \mu\text{m}$ exhalation 4 measurements
Medical face mask		98	99
Face mask, type A	C/TNT	90	92
Face mask, type B	C/C	83	79
Face mask, type C	C/C/C	83	77
Face mask, type D	TNT /TNT /TNT	96	97
Face mask, type E	TNT /C/TNT	92	93
Face mask, type F	TNT /C/TNT	96	96
Face mask, type G	TNT	92	92

C = cotton, TNT = non-woven fabric material; RSD% = 5 for 4 consecutive measurements

Table 2

Efficiency of selected tested face masks in function of particle dimensions.

	> 0.28	> 0.4	> 0.5	> 0.7	> 1.1	> 2.0	> 3.0	> 5.0
%Efficiency	97.3	97.9	98.2	97.6	98.0	100	100	100
Medical face-mask	6002	974	327	101	47	0	0	0
Aerosol	225873	45563	17871	4338	2335	224	116	70
%Efficiency	96.7	97.7	97.9	98.1	98.5	93.5	100	100
Face mask, type D	21519	3488	1298	342	151	24	0	0
Aerosol	641064	149745	62979	17653	9950	374	135	16
%Efficiency	84.4	85.3	85.2	85.2	84.5	76.7	81.3	100
Face mask, type C	58243	13175	5667	1632	932	62	23	8
Aerosol	372839	89863	38395	11063	5998	269	123	8
Nitrogen 2.8	198	30	6	0	0	0	0	0

masks as well as for testing the non-medical face masks using optical particle counter technique, which is used in EN 779:2012 to evaluate the filter filtration efficiency, combined with pump able to simulate the respiratory action with the aim to deliver a simple analytical system for screening test of medical and non-medical face masks in timely fashion.

CRedit authorship contribution statement

Luca Amendola: Conceptualization, Methodology, Writing - original draft. **Maria Teresa Saurini:** Investigation. **Francesco Di Girolamo:** Investigation, Writing - review & editing. **Fabiana Arduini:** Conceptualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] <https://apps.who.int/iris/handle/10665/330987> Accessed April 04, 2020.
- [2] <https://www.sciencemag.org/news/2020/03/would-everyone-wearing-face-masks-help-us-slow-pandemic> Accessed April 04, 2020.
- [3] <https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public> Accessed April 04, 2020.
- [4] <https://www.cdc.gov/coronavirus/2019-ncov/travelers/after-travel-precautions.html> Accessed April 04, 2020.
- [5] L. Bourouiba, Turbulent gas clouds and respiratory pathogen emissions: potential implications for reducing transmission of COVID-19, *JAMA* (2020), <https://doi.org/10.1001/jama.2020.4756> in press.
- [6] N. van Doremalen, T. Bushmaker, D.H. Morris, M.G. Holbrook, A. Gamble, B.N. Williamson, A. Tamin, J.L. Harcourt, N.J. Thornburg, S.I. Gerber, J.O. Lloyd-Smith, E. de Wit, V.J. Munster, Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1, *N. Engl. J. Med.* 382 (2020) 1564–1567, <https://doi.org/10.1056/NEJMc2004973> in press.
- [7] <https://www.theguardian.com/world/2020/apr/01/all-uk-hospital-staff-and-patients-should-wear-masks-says-doctors-group> Accessed April 04, 2020.
- [8] N.H. Leung, D.K. Chu, E.Y. Shiu, K.H. Chan, J.J. McDevitt, B. J., H.L. Yen Hau, Y. Li, D.K.M. Ip, J.S.M. Peiris, W.H. Seto, G.M. Leung, D.K. Milton, Respiratory virus shedding in exhaled breath and efficacy of face masks, *Nat. Med.* (2020), <https://doi.org/10.1038/s41591-020-0843-2> in press.
- [9] <https://european-accreditation.org/coronavirus-outbreak-accredited-laboratories-for-face-masks-testing/> Accessed April 04, 2020.
- [10] COMMISSION DECISION of 12 August 2002 implementing Council Directive 96/23/EC concerning the performance of analytical methods and the interpretation of results.
- [11] <https://www.agi.it/cronaca/news/2020-03-06/coronavirus-mascherina-toscana-7327076> Accessed April 04, 2020.
- [12] <https://www.regione.lombardia.it/wps/wcm/connect/0c81f5f1-ef90-4417-afe2-8d659c21b4ab/NOTA+TECNICA+2-1+-+Scheda+materiali+approvati.pdf?MOD=AJPERES&CACHEID=ROOTWORKSPACE-0c81f5f1-ef90-4417-afe2-8d659c21b4ab-n4n8iMs> Accessed April 04, 2020.
- [13] ASTM F2299 of 10 July 2003 Standard Test Method for Determining the Initial Efficiency of Materials Used in Medical Face Masks to Penetration by Particulates Using Latex Spheres.